SELECTED TOPICS IN OVERSET TECHNOLOGY DEVELOPMENT AND APPLICATIONS AT NASA AMES RESEARCH CENTER

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Invited presentation at the 6th Symposium on Overset Composite Grids & Solution Technology, Ft. Walton Beach, FL, October 8–10, 2002

Ames Research Center

OUTLINE

- Overview of overset activities at NASA Ames

- Recent developments in Chimera Grid Tools

- A general framework for multiple component dynamics

- A scripting approach to automating liquid rocket sub–systems simulations

- Critical future work for overset technology

OVERSET ACTIVITIES AT NASA AMES

Development

- Chimera Grid Tools (Chan, Rogers)
- PEGASUS 5 (*Suhs*, Rogers, *Dietz*)
- OVERFLOW chemistry (Olsen, et al.)
- INS3D multi–level parallelizm (Kiris)
- XML4CFD (Murman, Chan, Aftosmis, Meakin)
- AeroDB (Rogers, Aftosmis, Tejnil, Ahmad, Pandya, ...)
- ASG auto surface gridding (Klopfer, Onufer) [restart FY03?]

I

- OVERFLOW–D (Meakin, Potsdam)

A

Applications

- Liquid rocket engine subsystems (Kiris, Chan, Kwak)
- Liquid Glide Back Booster under AeroDB (Chaderjian)
- Cardiovascular system – assist devices, arteries (Kiris, Kwak)
- Harrier in ground effect (Chaderjian, et al.) [not active]

I

- Rotorcraft (Meakin, Potsdam, Strawn, Dimanlig, ...)
- Missiles (Meakin, Nygaard)

A

IMPLEMENTATION OF CHEMISTRY IN OVERFLOW

Collaborators: M. Olsen, S. Venkateswaran, D. Prabhu, T. Olsen, Y. Liu, M. Vinokur

Premixed Equilibrium Chemistry

– N–S eq. with arbitrary eq. of state, element ratio constant over space and time
– computation speed comparable with perfect gas

General (Non–Premixed) Equilibrium Chemistry

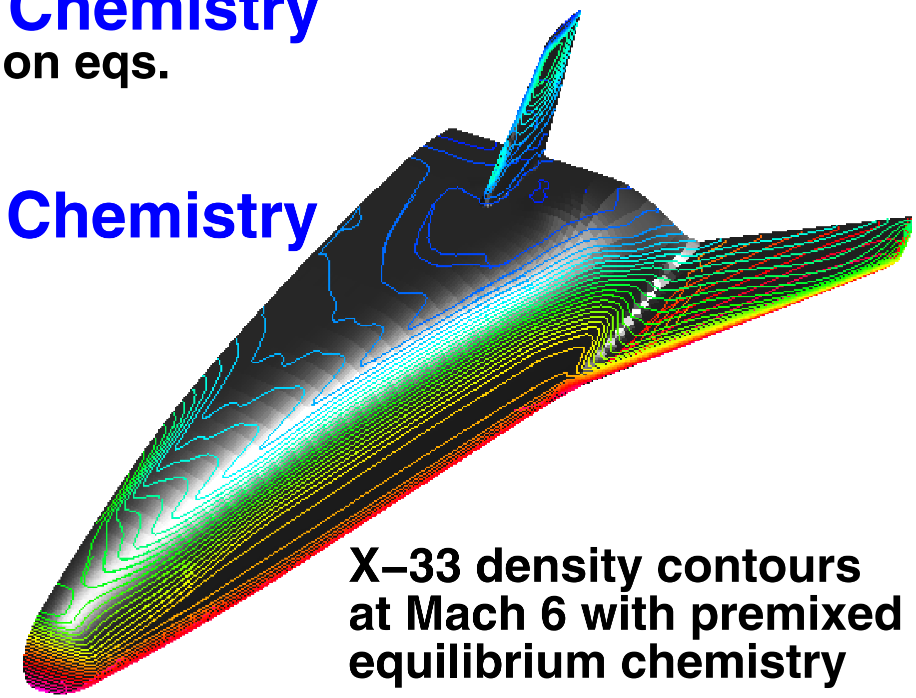
– N–S, species convection, equilibrium composition eqs.
– robust reacting capability

Computationally Efficient Finite Rate Chemistry

– N–S, species convection, rate eqs.
– general reacting flow capability

Features

– general thermodynamic model (not tied to a particular functional form)
– computational efficiency
– general mixtures of perfect gases



X–33 density contours at Mach 6 with premixed equilibrium chemistry

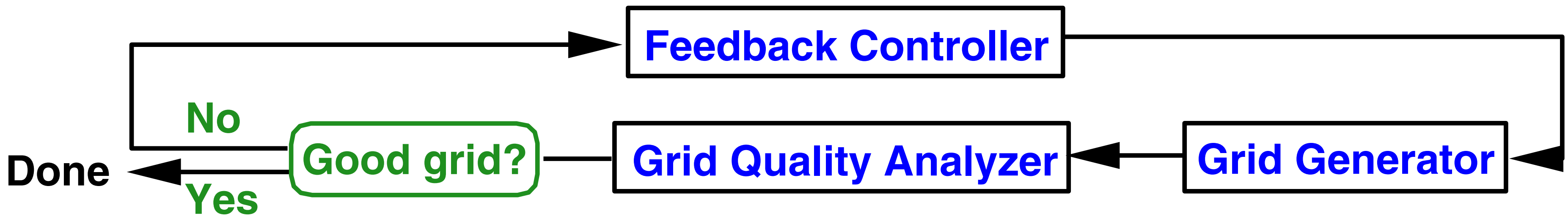
Papers to be presented at 41st AIAA Aerospace Sciences Meeting & Exhibit, Jan., 2003.

Olsen, M. E., Liu, Y., Vinokur, M. and Olsen, T., Implementation of Premixed Equilibrium Chemistry Capability in OVERFLOW, AIAA Paper 2003–0962.

Olsen, M. E., Venkateswaran, S., Prabhu, D. K. and Olsen, T., Implementation of Finite Rate Chemistry Capability in OVERFLOW, AIAA Paper 2003–0963.

ASG AUTOMATIC SURFACE GRIDDING

Collaborators: Goetz Klopfer, Jeff Onufer (restart FY 03 ?)



Grid Generator

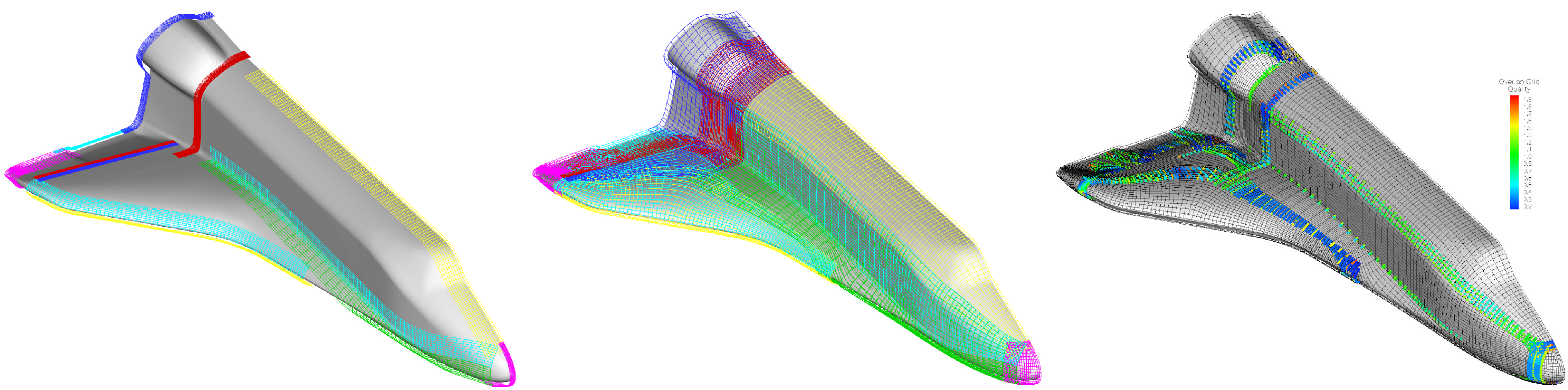
– SURGRD hyperbolic/algebraic surface grid generator

Grid Quality Analyzer

– single grid (grid–induced truncation error)
– overlap grid (relative volume, cell–difference, stencil quality)

Feedback Controller

– re–adjusts grid generator inputs based on grid quality
– iterate until grid quality criteria are satisfied

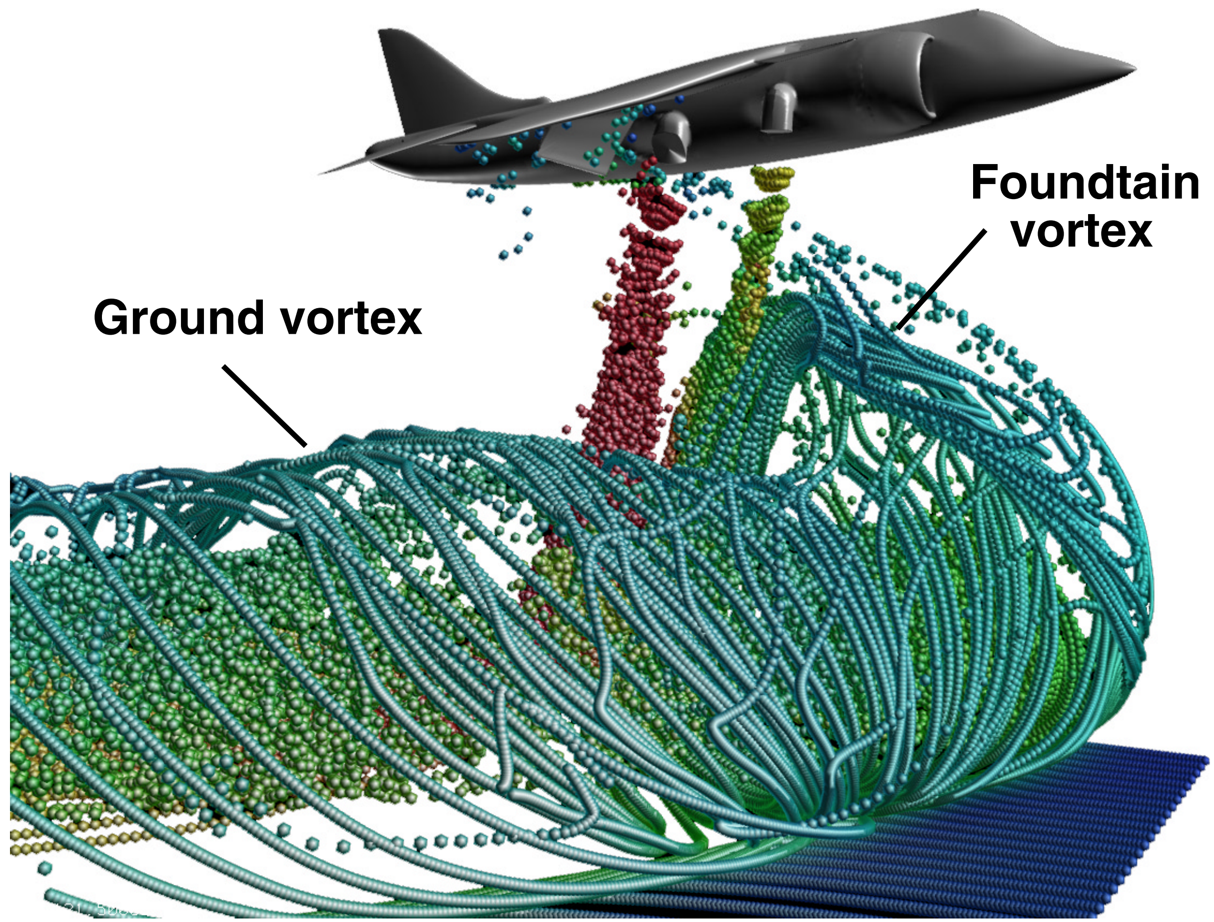


HARRIER UNSTEADY DATABASE GENERATION

Collaborators: N. Chaderjian, J. Ahmad, S. Pandya, S. Murman

Motivation: Safety

–hot gas ingestion
–suck–down effect
–ground personnel



Objectives

- reduce process time to generate database
- demonstrate ability to capture unsteady flow structures & frequency

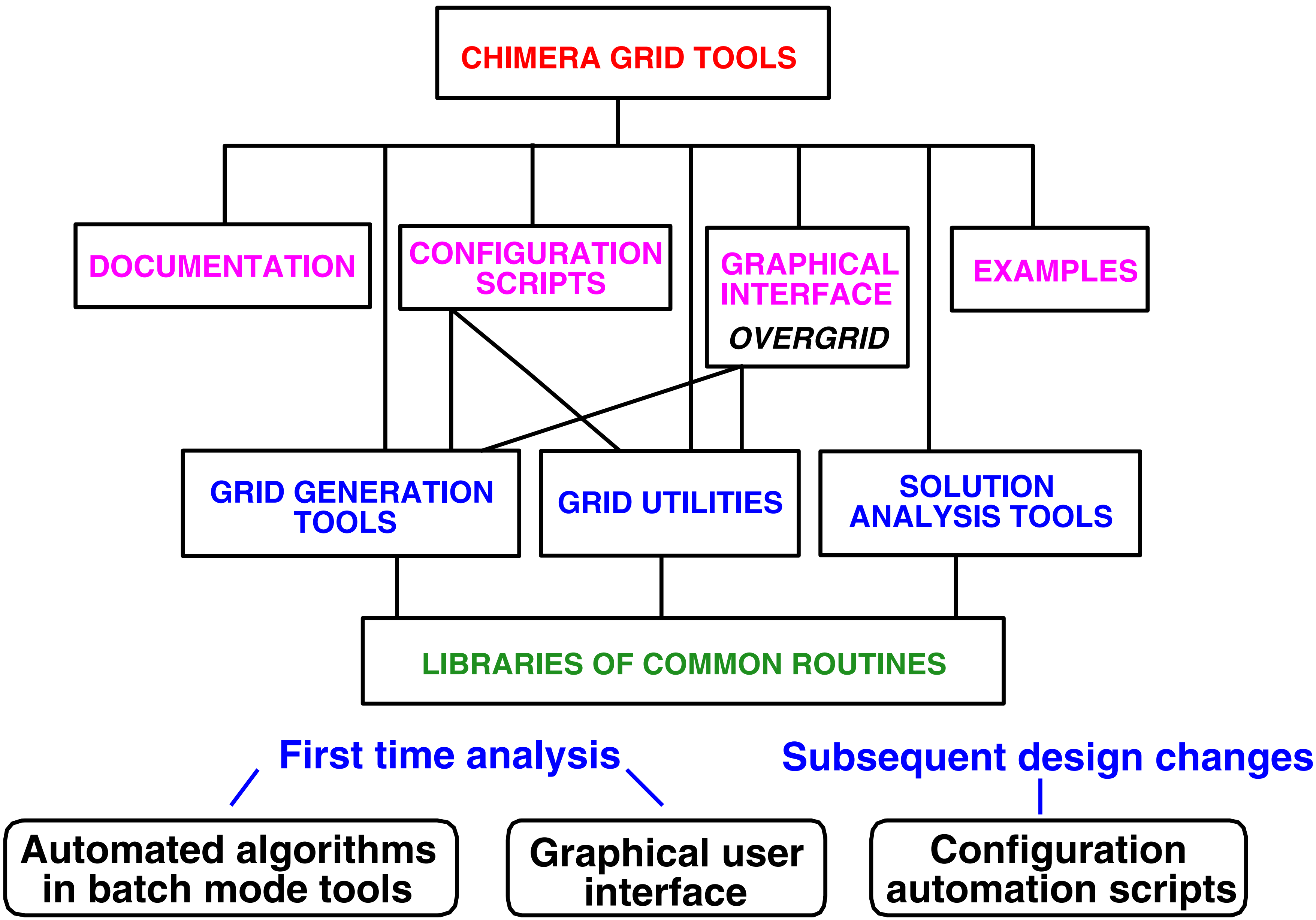
Results

- 35 time accurate RANS solutions (4 million pts) in 1 week using OVERFLOW (952 dedicated Origin processors, AIAA 2002–3056)
- captured low frequency oscillations (0.5 Hz)
- captured unsteady flow structures
- developed Dbview GUI for local/remote access of database

CHIMERA GRID TOOLS (CGT)

Collaborators: William Chan, Stuart Rogers, Steve Nash, Pieter Buning, Bob Meakin

Objective – reduce overall Chimera CFD analysis time



RECENT DEVELOPMENTS IN CGT

Version 1.7 released in July, 2002

Main new features in OVERGRID

- Advanced diagnostics
- Auto boundary conditions selection and display
- OVERFLOW−D function calls
- Component hierarchy and dynamics module
- Faster I/O and reduction on peak memory requirement

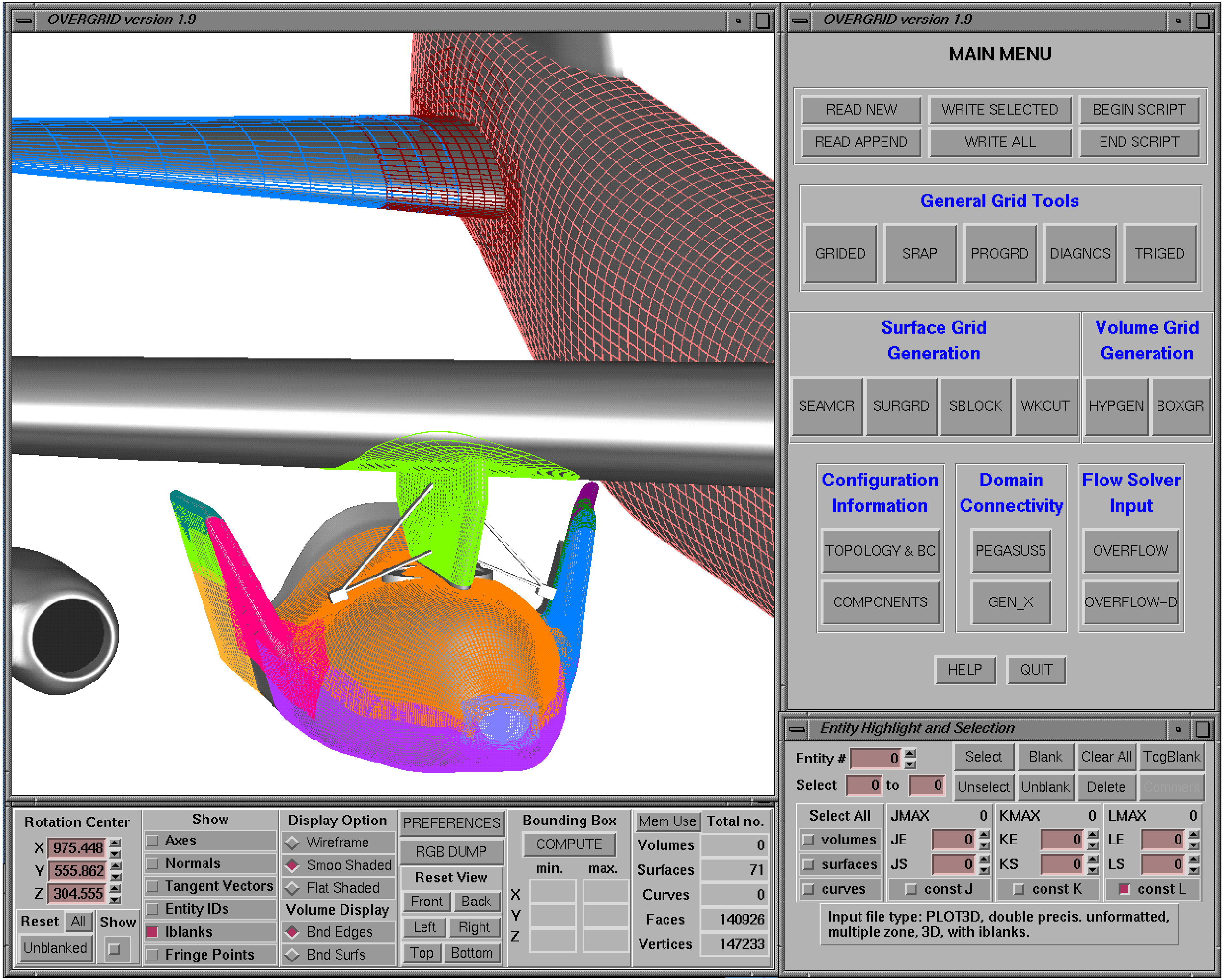
Recent publications at 32nd AIAA Fluid Dynamics Conference, St. Louis, Missouri, June, 2002

Chan, W. M., The OVERGRID Interface for Computational Simulations on Overset Grids, AIAA Paper 2002–3188.

Chan, W. M., Gomez, R. J., Rogers, S. E. and Buning, P. G.,
Best Practices in Overset Grid Generation, AIAA Paper 2002–3191.

Suhs, N. E., Rogers, S. E. and Dietz, W. E., PEGASUS 5: An Automated Pre−processor for Overset−Grid CFD, AIAA Paper 2002–3186

OVERGRID'S MAIN WINDOWS (version 1.9)



ADVANCED DIAGNOSTICS MODULE

Grid wireframe colored by
- structured grid quality
- surface triangulation quality
- scalar function on triangulation

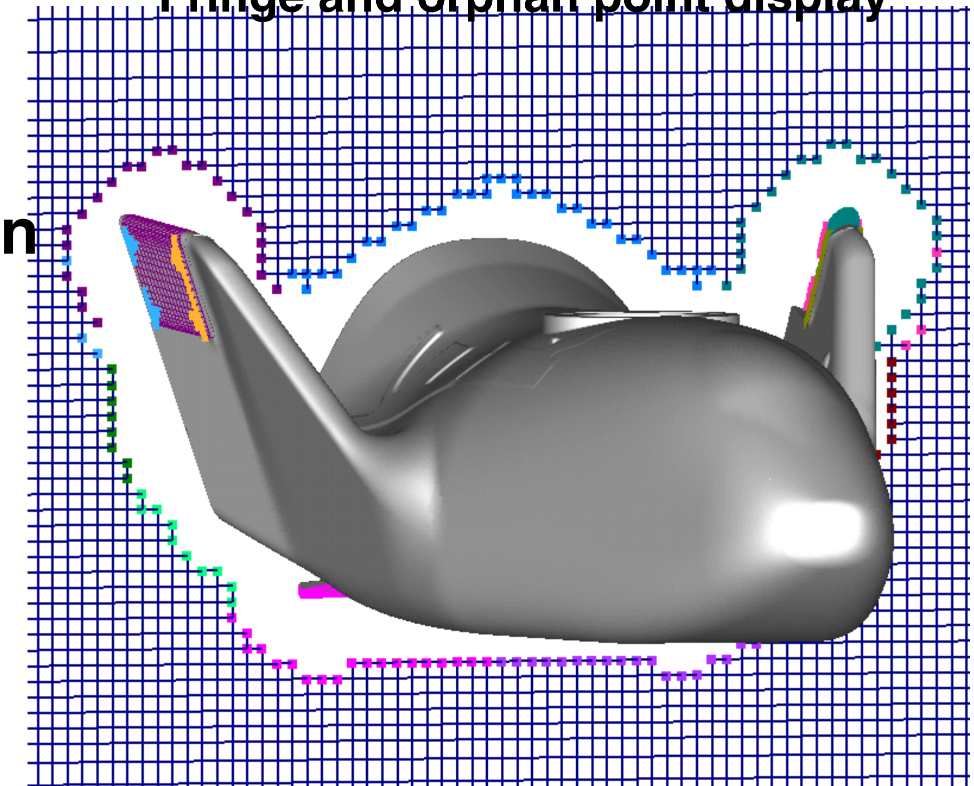
Orphan points
- display all or by grid

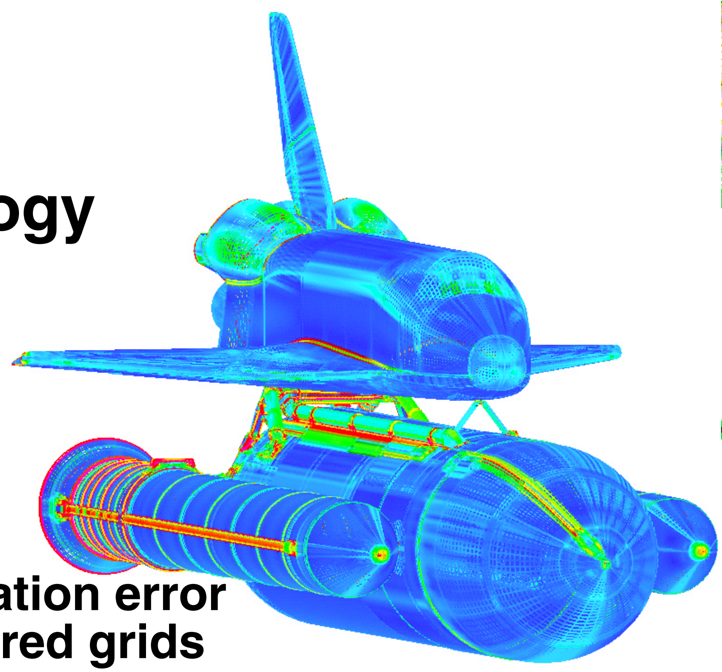
Iblank statistics
- % blanked
- % fringe

Negative Jacobian
- report by grid

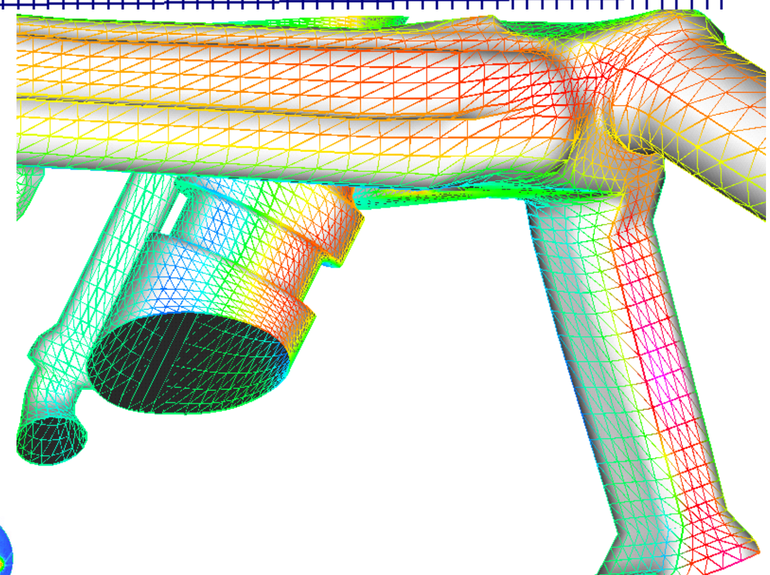
Surface grid topology
- check
- reset

Fringe and orphan point display





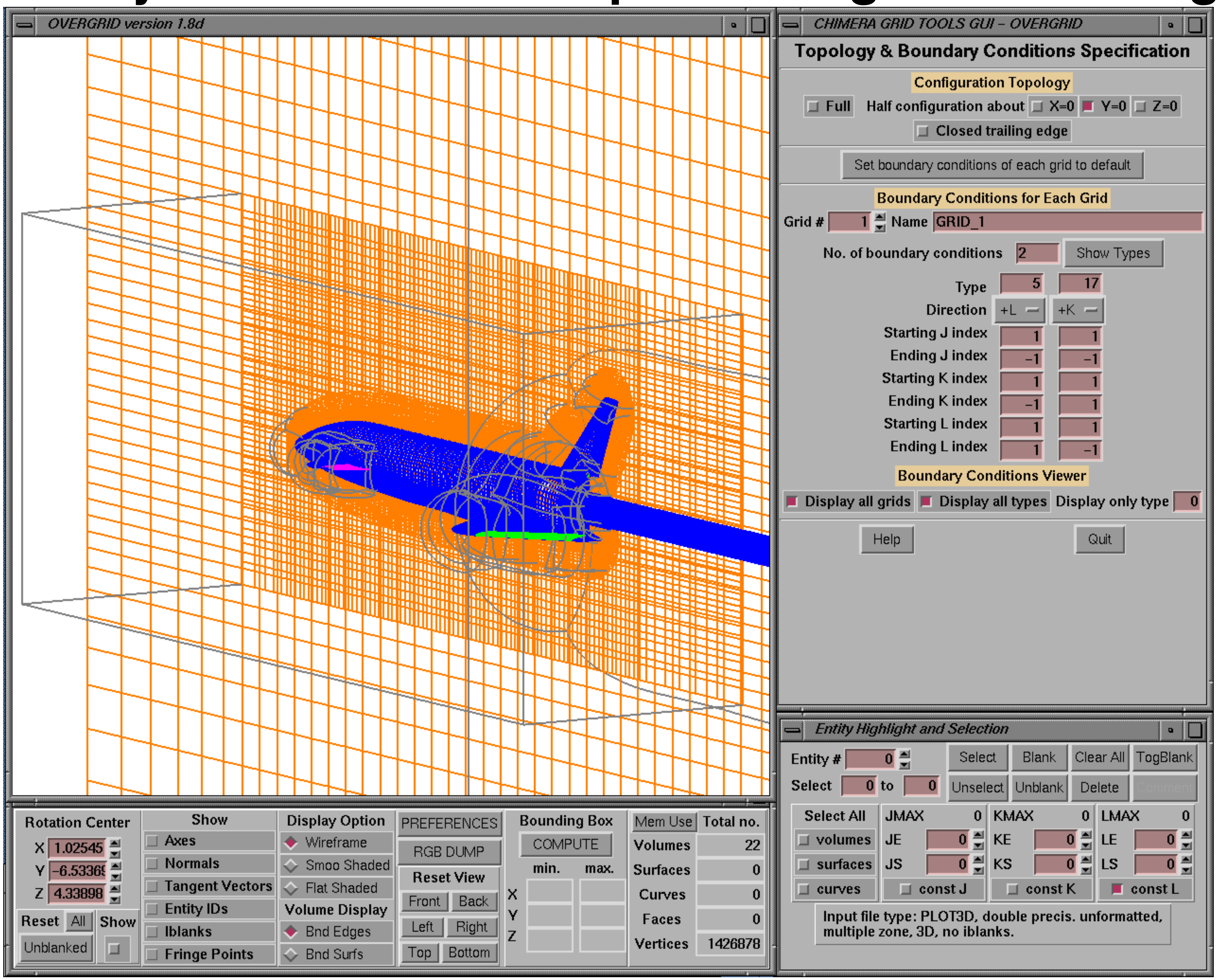
Grid induced truncation error estimate on structured grids



Scalar function on surface triangulation, e.g., pressure

AUTO BOUNDARY CONDITIONS SELECTION AND DISPLAY

- Auto selection of topological and wall boundary conditions
- Widgets for fast manual override if needed
- Surfaces colored by b.c. type for quick visual check
- Very fast flow solver input for large number of grids



Orange = symmetry plane

Dark blue = viscous wall

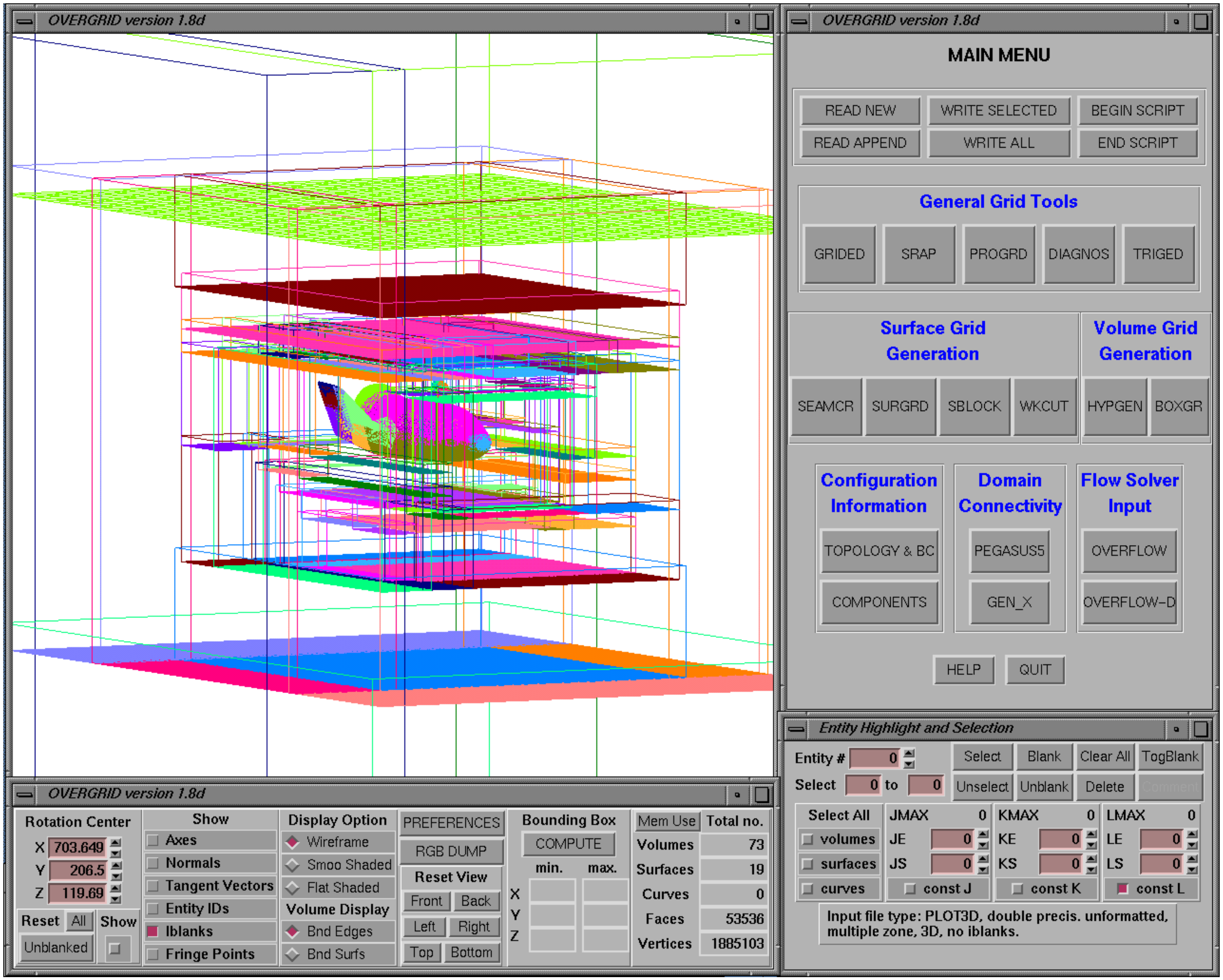
Green = periodic

Magenta = wake cut

Total of 48 b.c. types supported

OFF–BODY CARTESIAN GRID GENERATION AND DOMAIN CONNECTIVITY USING OVERFLOW–D

– Module for auto multi–level off–body Cartesian grid generation
– Module for creating object X–rays for hole cutting
– Module for specifying hole cutting information and input creation for OVERFLOW–D/DCF



TO–DO LIST FOR CHIMERA GRID TOOLS

– More robust hybrid surface grid generation tool (quads and triangles) for forces and moments computation

– Surface grid generation time reduction

  > More automatic surface curve creation
  > More automatic domain decomposition
  > OVERGRID interface for ASG algorithm/software

– Surface grid generation on CAD – investigate CAPRI interface

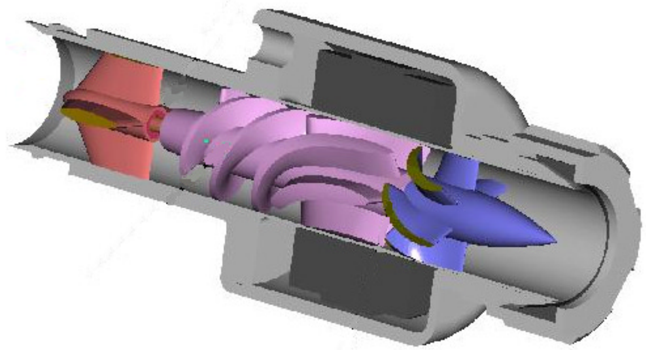
– More coordination between graphical interface and scripts

– Approx. 80 other items for improvements to CGT and overset technology

A SAMPLE OF APPLICATIONS WITH MULTIPLE COMPONENTS IN RELATIVE MOTION

Space Launch Vehicles

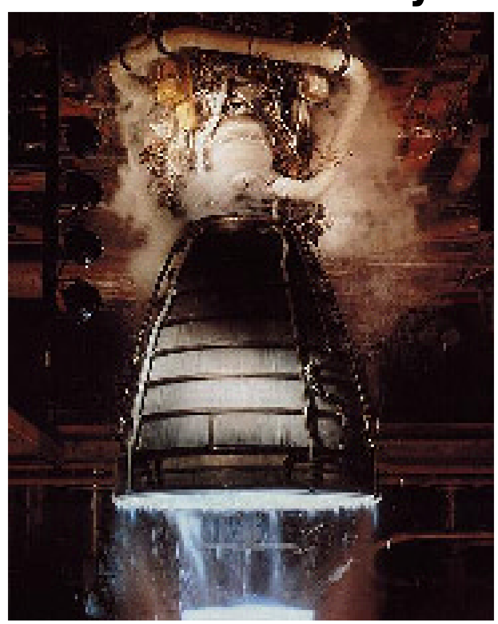
Heart Assist Devices



Missiles

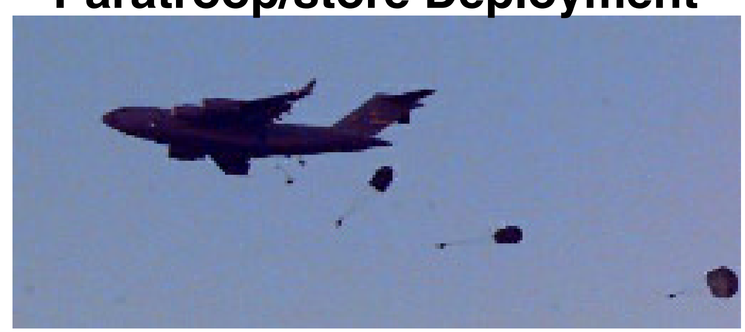
Aircraft Control Surfaces

Turbomachinery



Rotorcraft

Paratroop/store Deployment



A FRAMEWORK FOR MULTIPLE COMPONENT DYNAMICS

Collaborators: Scott Murman, William Chan,
Mike Aftosmis, Bob Meakin

Motivation

– Computations involving multiple complex bodies in relative motion have been scarce mainly because
  > intensive CPU time required
  > problem definition is difficult and not standardized
– Potential benefit for a variety of NASA and DOD programs

Objective

– Develop common framework that can be used by different kinds of flow solvers (structured or unstructured)
  OVERFLOW–D (structured overset)
  FLOWCART (unstructured Cartesian)

Approach

– Use XML files as information exchange format between GUI (for problem setup) and flow solvers
– Develop API for reading/writing the XML files (XML4CFD) (C and f90 versions)

FRAMEWORKS

Configuration

– Components hierarchy and relationship to grids, geometry, virtual surfaces, etc.

Scenario

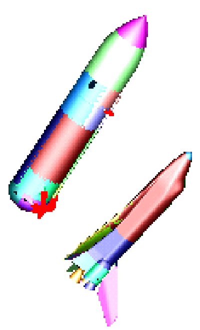
– Rigid–body dynamics of components
  > prescribed motion
  > motion under aerodynamic loads
    – unconstrained 6–dof
    – constrained
    – controlled

Configuration Space

– A set of configurations defined by parameterizing certain attributes of a baseline configuration (e.g., a space launch vehicle with a range of elevon settings)

CONFIGURATION FRAMEWORK

- A configuration is a collection of rigid components
- Each component is allowed one immediate parent and can move relative to its parent
- A root component has no parent and can move relative to other root components under an inertial coordinate system
- A component can be of type struc, tri or container
- Struc and tri components can have associated geometry/grids
- A component can be moved to its initial position via a set of transforms (a prescribed sequence of rotation, translation, and mirror commands)



```
<Component Name="Body flap" Parent="Orbiter" Type="struc">
  <Data> <Grid List="9, 11–13" /> </Data>
  <Transform>
    <Rotate Center="90.0,0.0,0.0" Axis="0.0,1.0,0.0" Angle="10"
  </Transform>
</Component>
```

SCENARIO FRAMEWORK

– A scenario is a collection of prescribed or aero6dof motions

– Each prescribed or aero6dof motion describes the dynamics of a component over a period of time

– Each component may have different motions during different periods of time

– Each prescribed motion is a sequence of rotations and translations over a time period where the velocity components and angular speeds can be arbitrary functions of time

```
<Prescribed Component="Orbiter" Start="0.0" End="1.0">
  <Translate Velocity="0.0, 0.0, 3.0*t^2" />
  <Rotate Center="0.5,0.0,1.0" Axis="0.0,1.0,0.0" Speed="sin(0.5*pi*t)"/>
</Prescribed>
```

– Each aero6dof motion requires the input of the component’s

> mass and center of mass

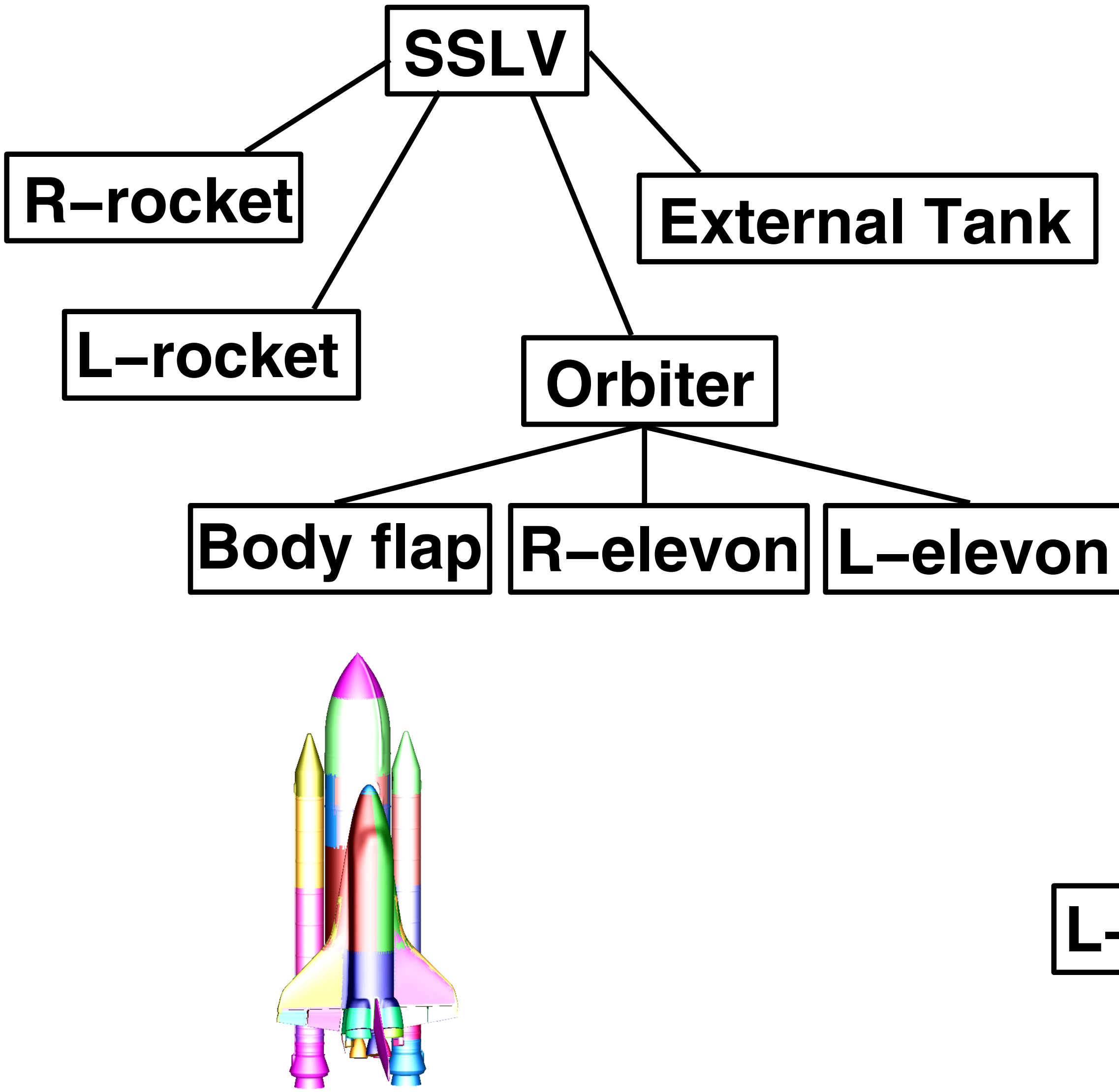
> moments of inertia and directions of principal axes

> external forces and moments (gravity, etc.)

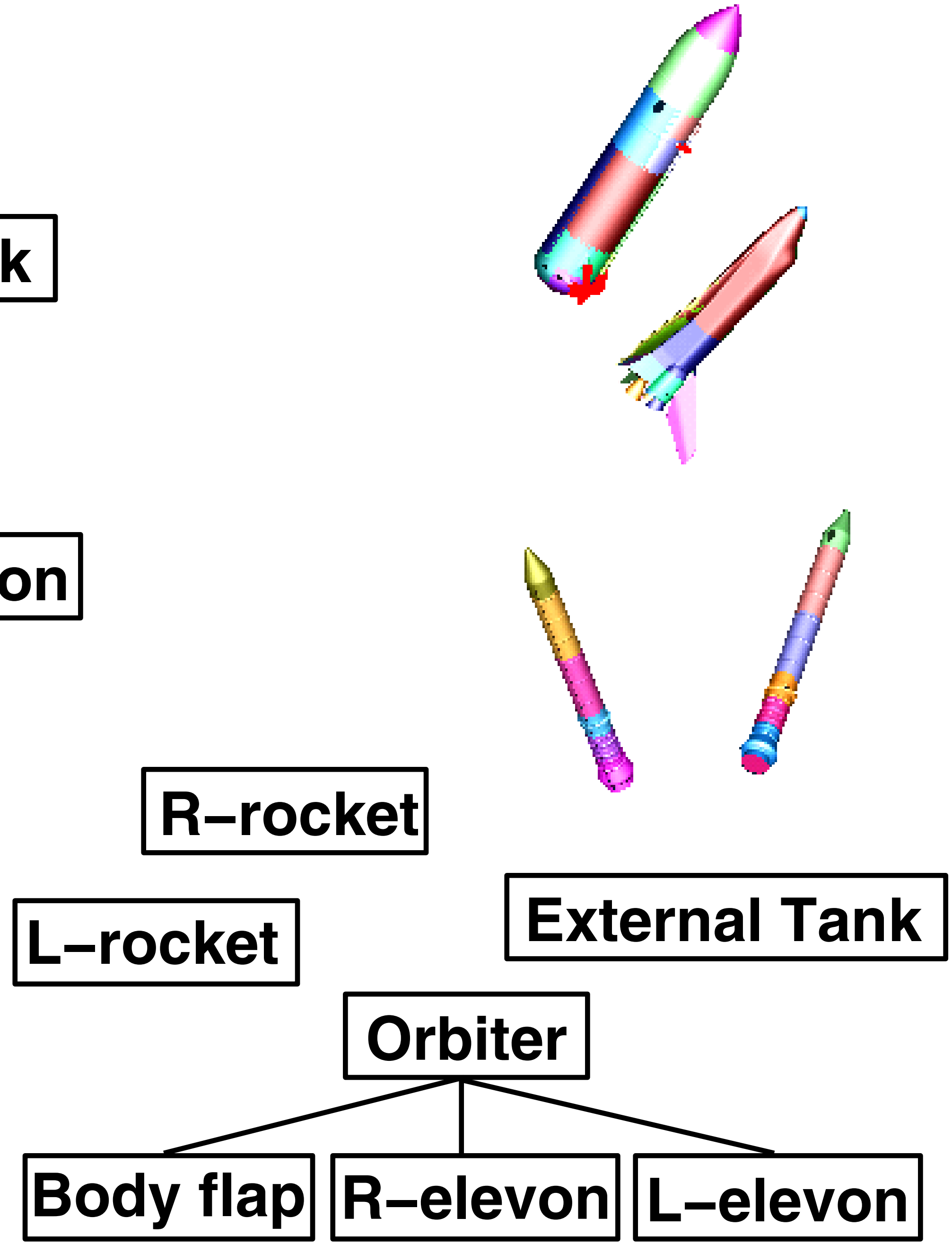
> constraints

SPACE SHUTTLE LAUNCH VEHICLE
PARENT/CHILD COMPONENT HIERARCHY

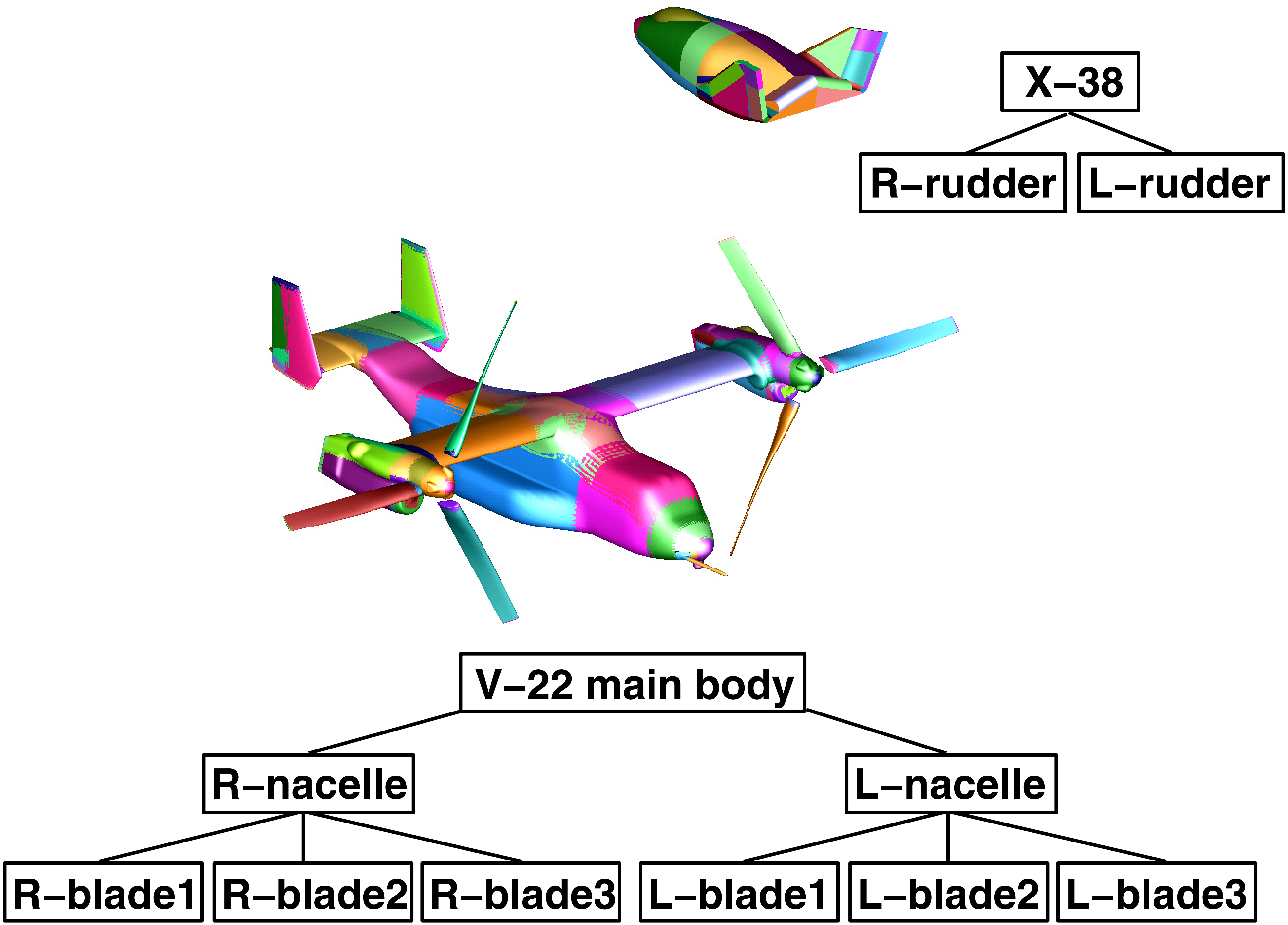
Pre–separation



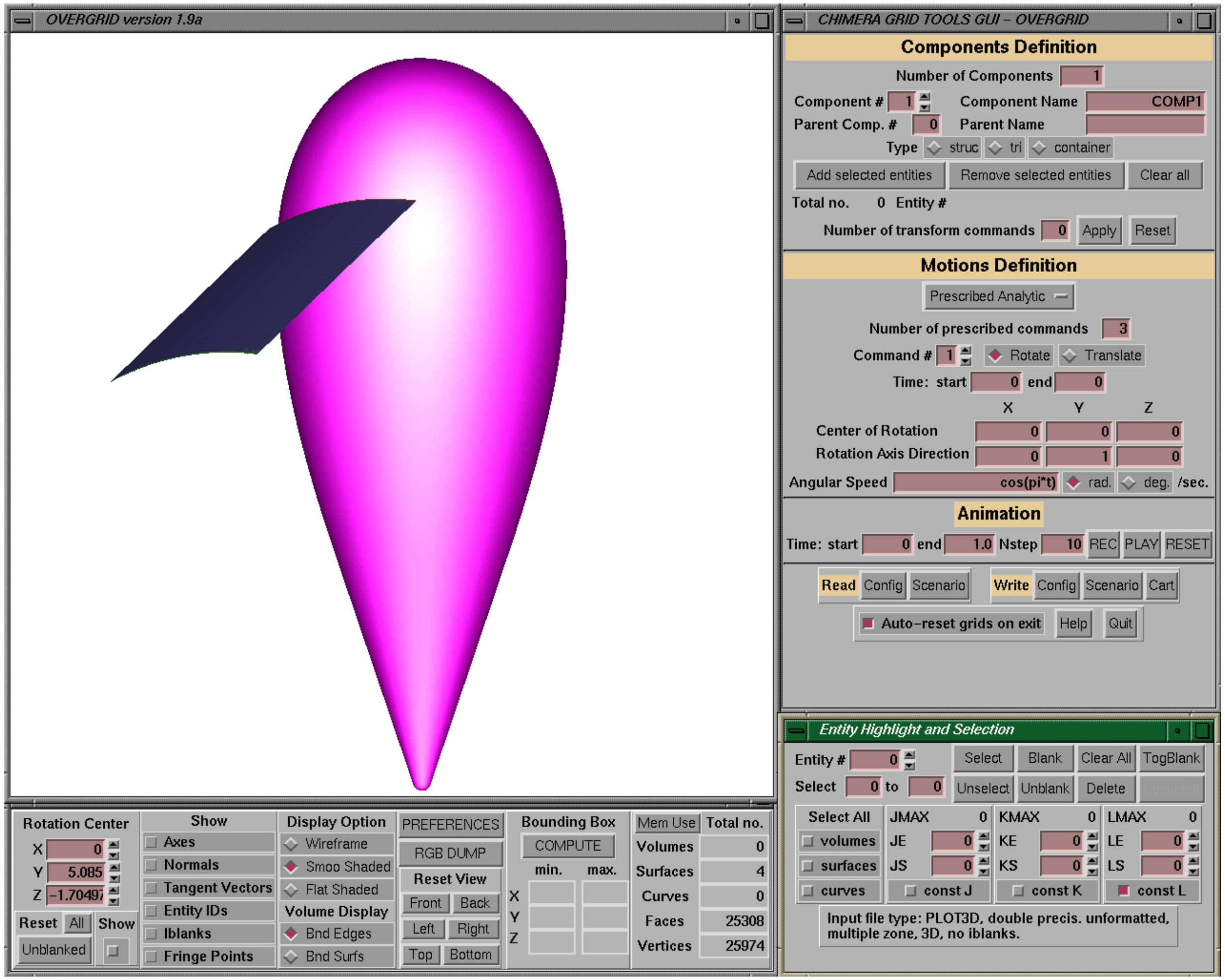
Post–separation

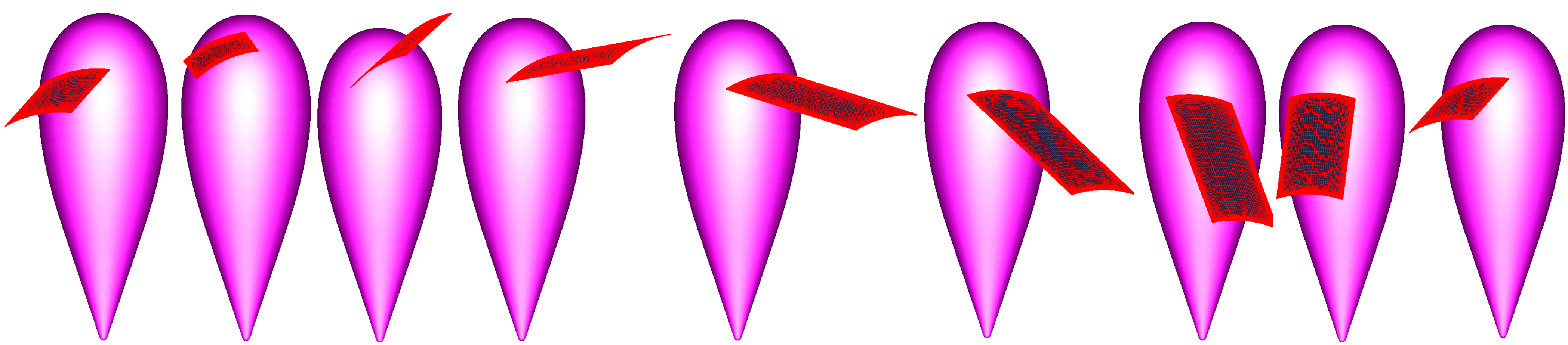


V–22 AND X–38 PARENT/CHILD COMPONENT HIERARCHY



DEMONSTRATION OF FLAPPING WING IN SCOOPING MOTION





CURRENT STATUS AND FUTURE PLANS

Current status

OVERGRID – specification and animation of components hierarchy and dynamics for prescribed motion, read/write XML files for interfacing with flow solvers

OVERFLOW–D (1.5e) and FLOWCART– read Config and Scenario XML files for driving prescribed motions

Future plans

Config – configuration space, ‘clone’ component type

Scenario – prescribed motion with table lookup, aero6dof motion with constraints, controlled/mixed motions

More details in paper:

**Murman, S. M., Chan, W. M., Aftosmis, M. J., and Meakin, R. L.,
An Interface for Specifying Rigid–Body Motion for CFD Applications,
AIAA Paper 2003–1237, 41st AIAA Aerosciences Meeting and Exhibit, January, 2003.**

SCRIPT DEVELOPMENT FOR TURBOPUMP SIMULATIONS

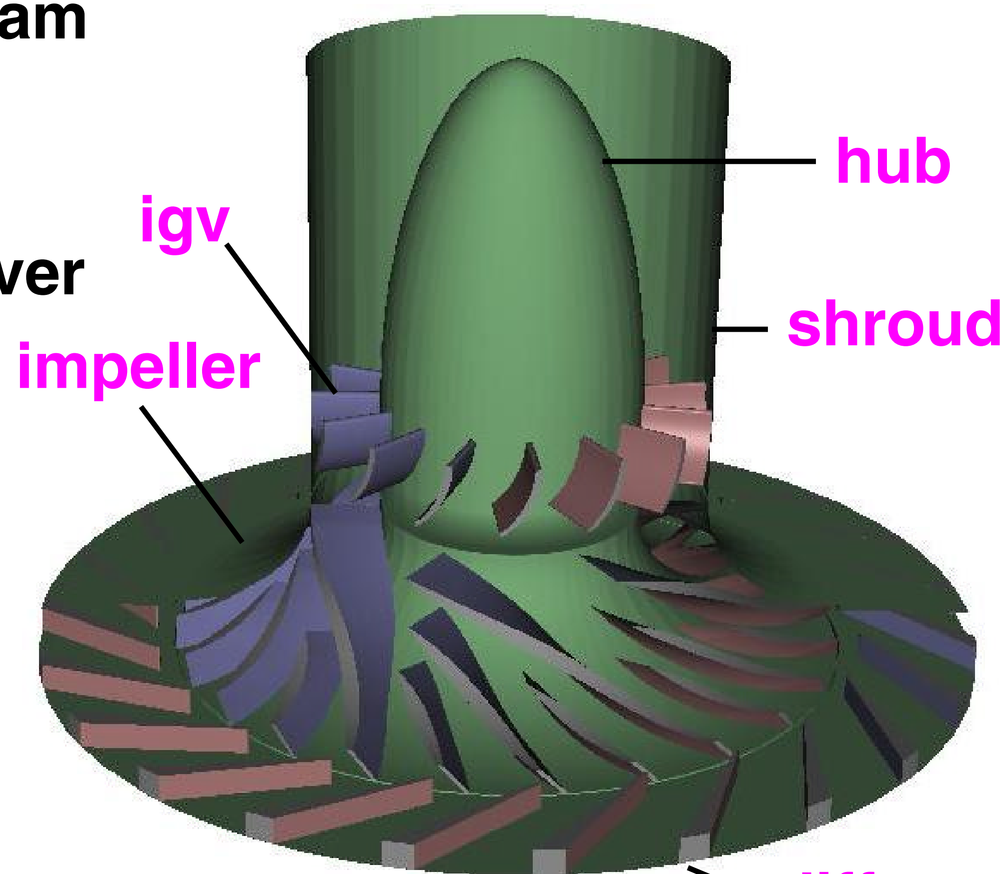
Collaborators: Cetin Kiris, William Chan, Dochan Kwak

Motivation

Support 2nd generation RLV program with high fidelity viscous analysis

Significant user's effort needed in process from geometry to flow solver

How coarse can a grid system be and still provide accurate results?



Objective

Develop script system to generate grids, create domain connectivity and flow solver inputs for different components of complete turbopump automatically

GEOMETRY → Turbopump Scripts → DCF → FLOW SOLVER

Turbopump Scripts: grids | domain connectivity input | flow solver input

APPROACH

General Gridding Strategy

- Create grid system for each component independently and use ring grids for communication between components

First Generation Scripts

- One specialized script for each component with optional rings at inflow and outflow boundaries
- Manual assembly of grids/inputs from different components

Second Generation Scripts

- Single master script that allows the user to specify any combination of components and rings

- Master script calls generic component and ring scripts

- Generic component script can handle geometry for inducer, inlet guide vanes, impeller and diffuser

- Generic ring script can handle ring grid topology for inflow, outflow, and between components

SCRIPT GENERATION

Disadvantages

– Require expertise to build scripts the first time

Advantages

– Allow rapid re–run of entire process

– Easy to do grid refinement and parameter studies

– Easy to try different gridding strategies

– Documentation of gridding procedure

Tcl scripting language

– Works on UNIX, LINUX and WINDOWS

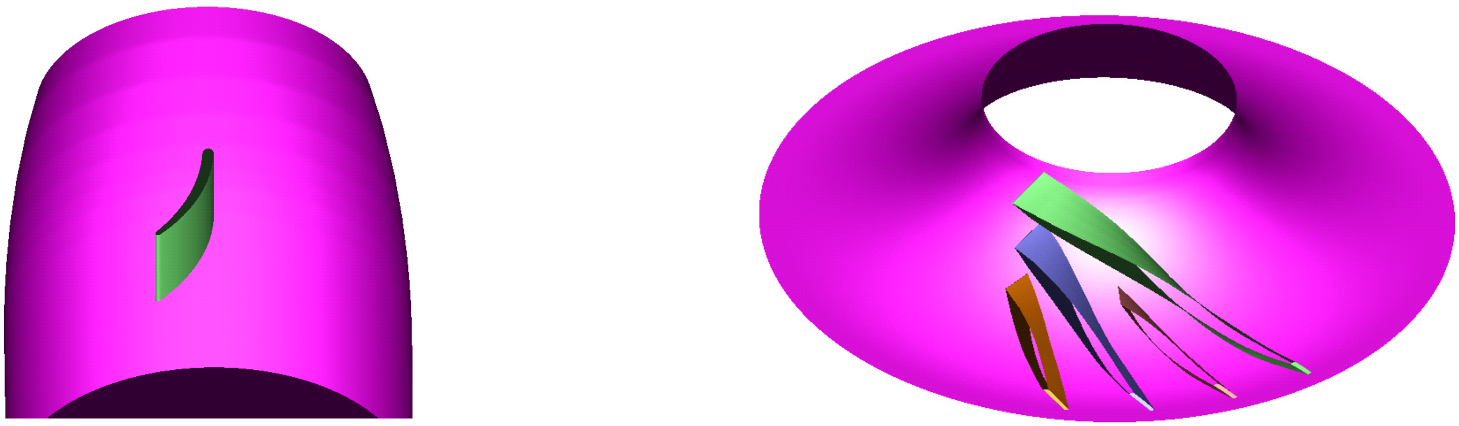
– Integer and floating point arithmetic capability

– Modular procedure calls

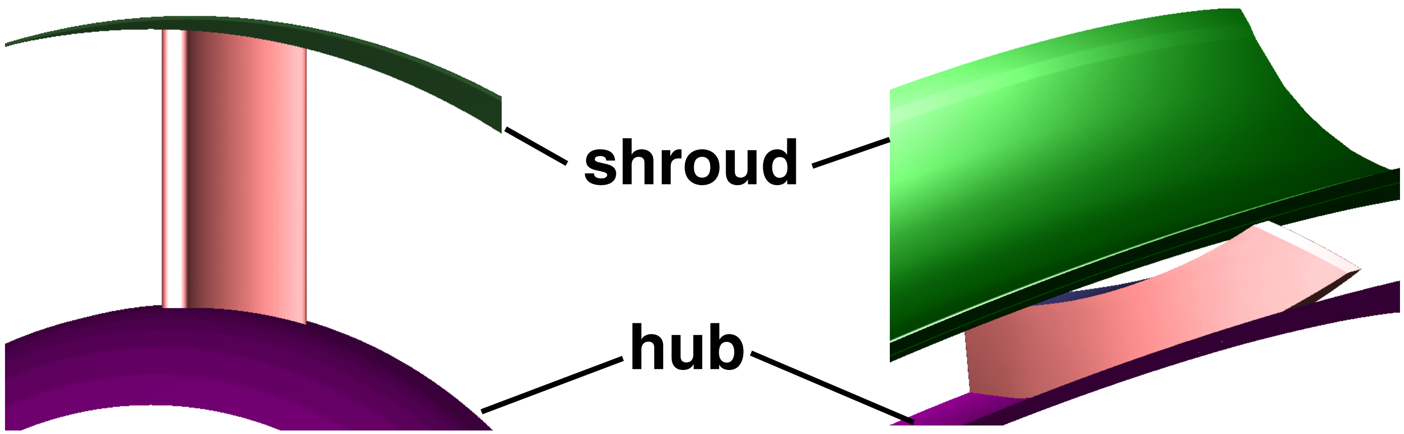
– Easy to add GUI later if needed

COMPONENT GEOMETRY PARAMETERS

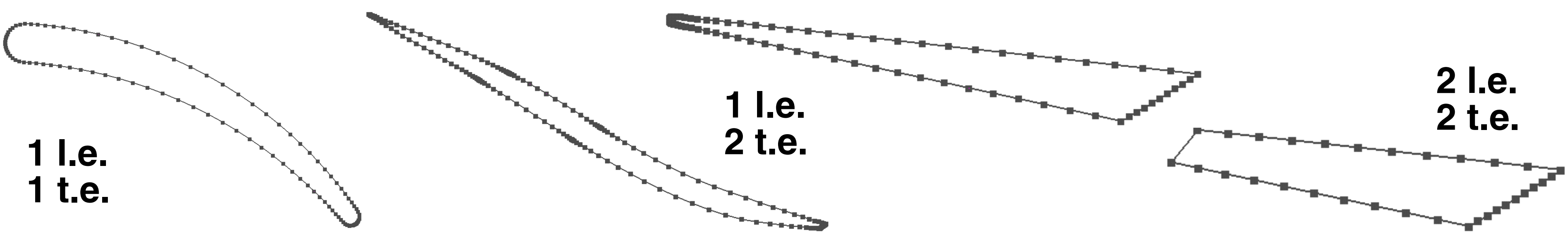
– number of sections and number of distinct blades per section



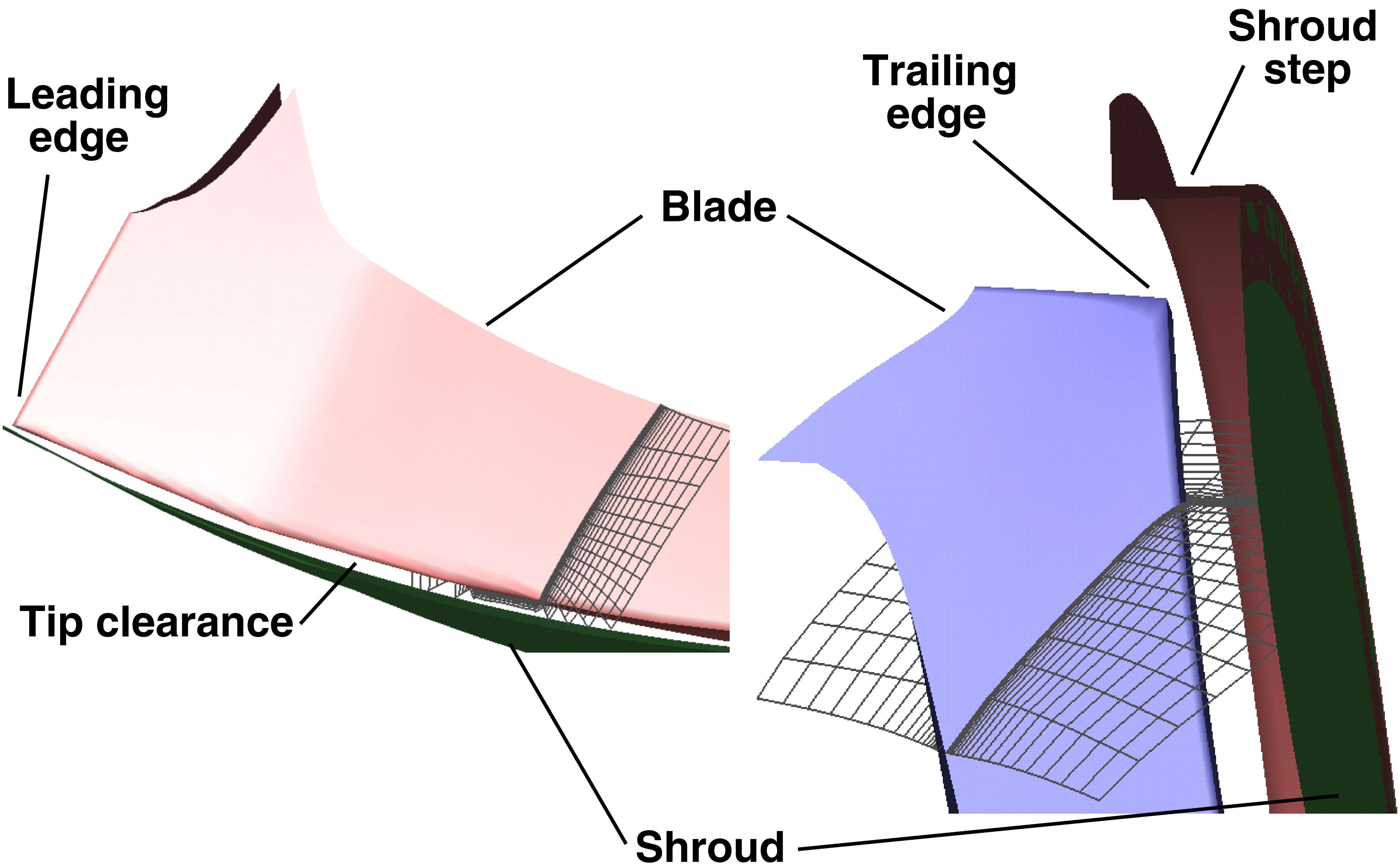
– no tip clearance / tip clearance no step / tip clearance with step



– 1 or 2 control points at blade leading/trailing edges



IMPELLER BLADE TIP CLEARANCE AND SHROUD STEP



INPUT AND OUTPUT

Input

- profile curves for hub and shroud in PLOT3D format (rotated by script to form surface of revolution)

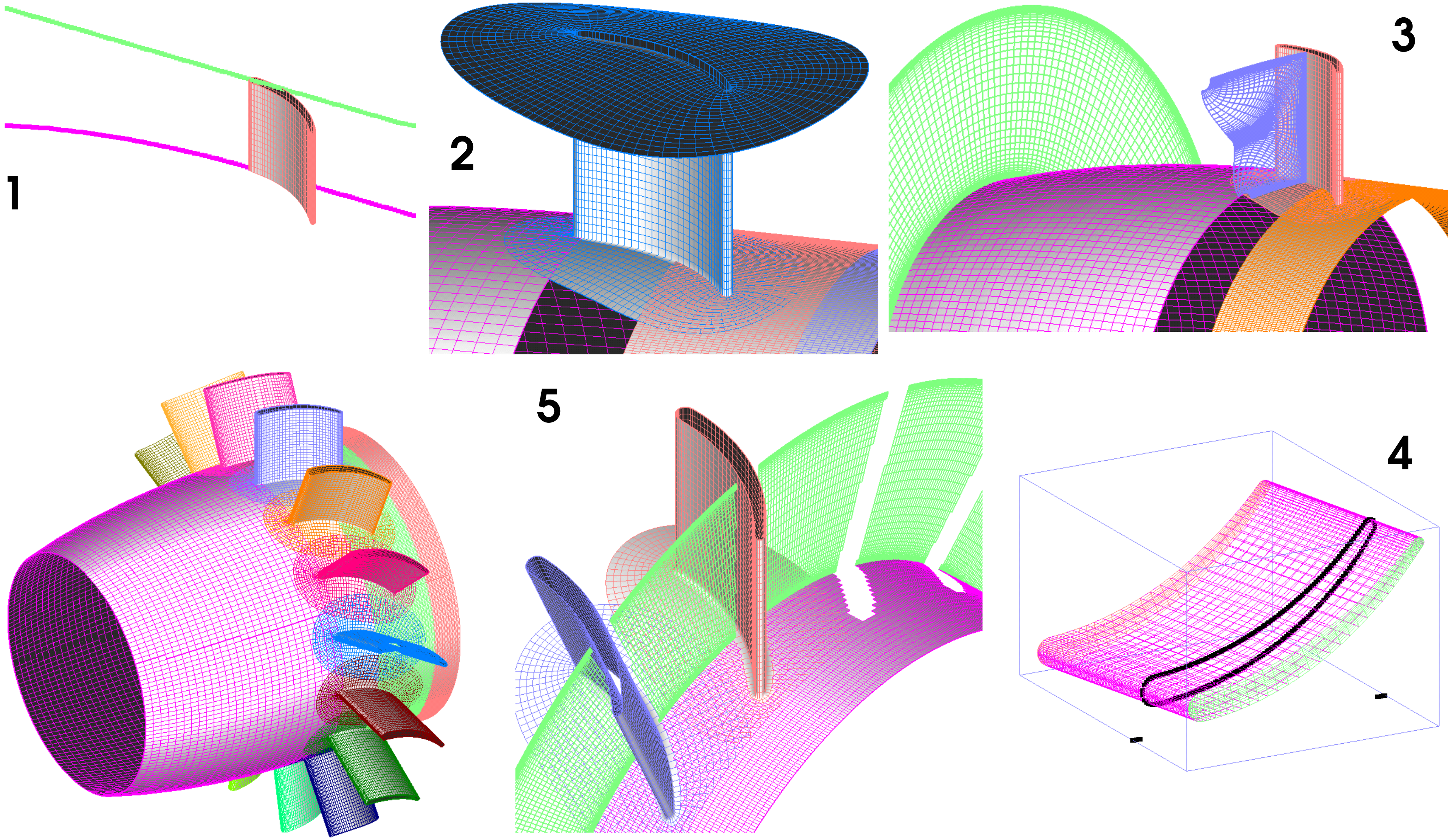
- blade (and tip) surfaces in PLOT3D format

- Parameters that can be changed
  - number of blades and sections
  - global surface grid spacing Δs_g (on smooth regions)
  - local surface grid spacing, some independent (e.g., leading/ trailing edge spacing) and some expressed as multiples of Δs_g (e.g., blade span spacing)
  - viscous wall normal grid spacing
  - marching distances
  - grid stretching ratio

Output

- overset surface and volume grids for hub, shroud, blades
- object X–rays for hole cutters using DCF
- domain connectivity namelist input for OVERFLOW–D

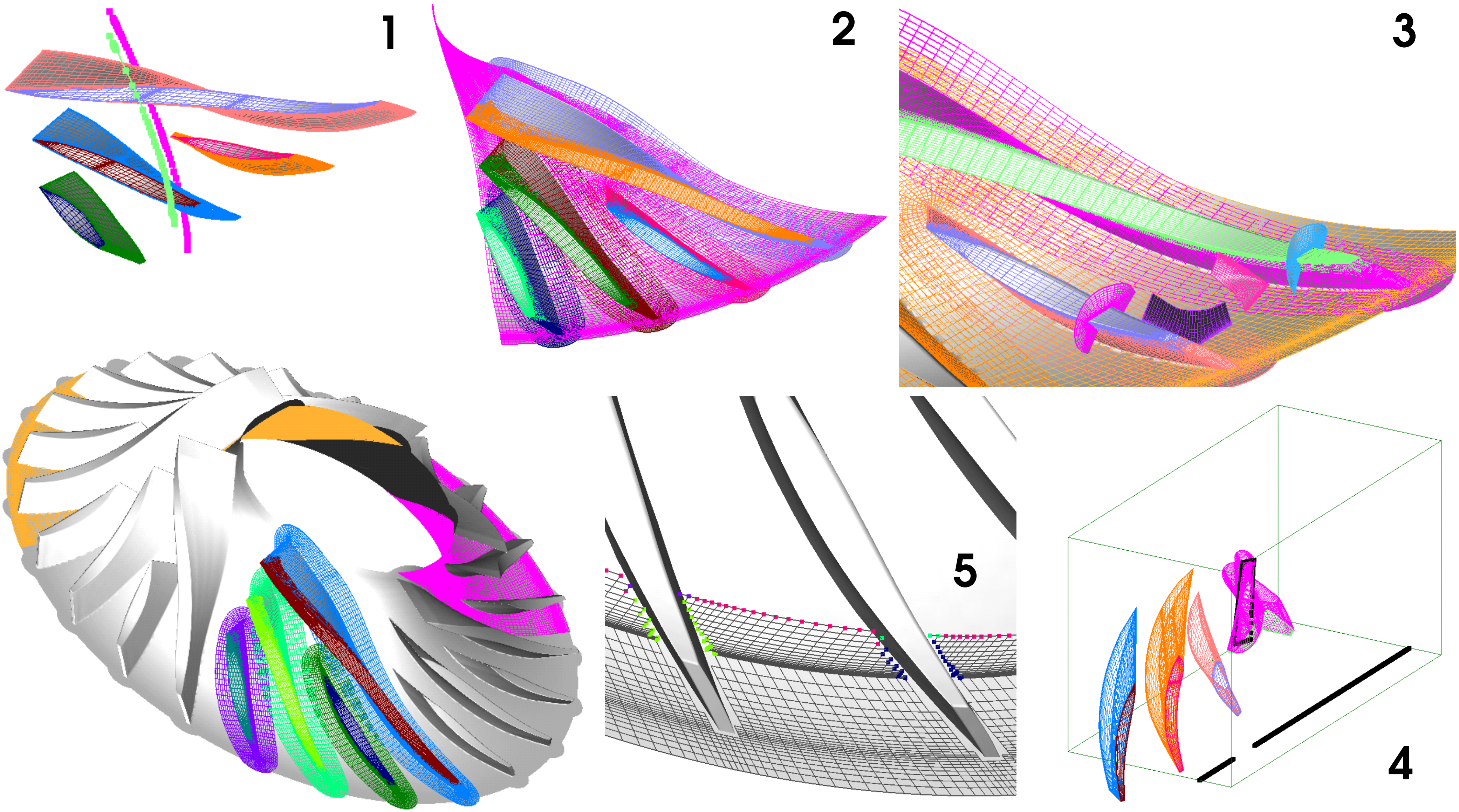
INLET GUIDE VANES (N repeated blades, no tip clearance)



	Manual	Script (fine)	Script (coarse)
No. of pts (million)	7.1	5.8	1.1
User time *	1 day	43 sec.	20 sec.

(* from geometry def. to DCF input with SGI R12k 300MHz CPU)

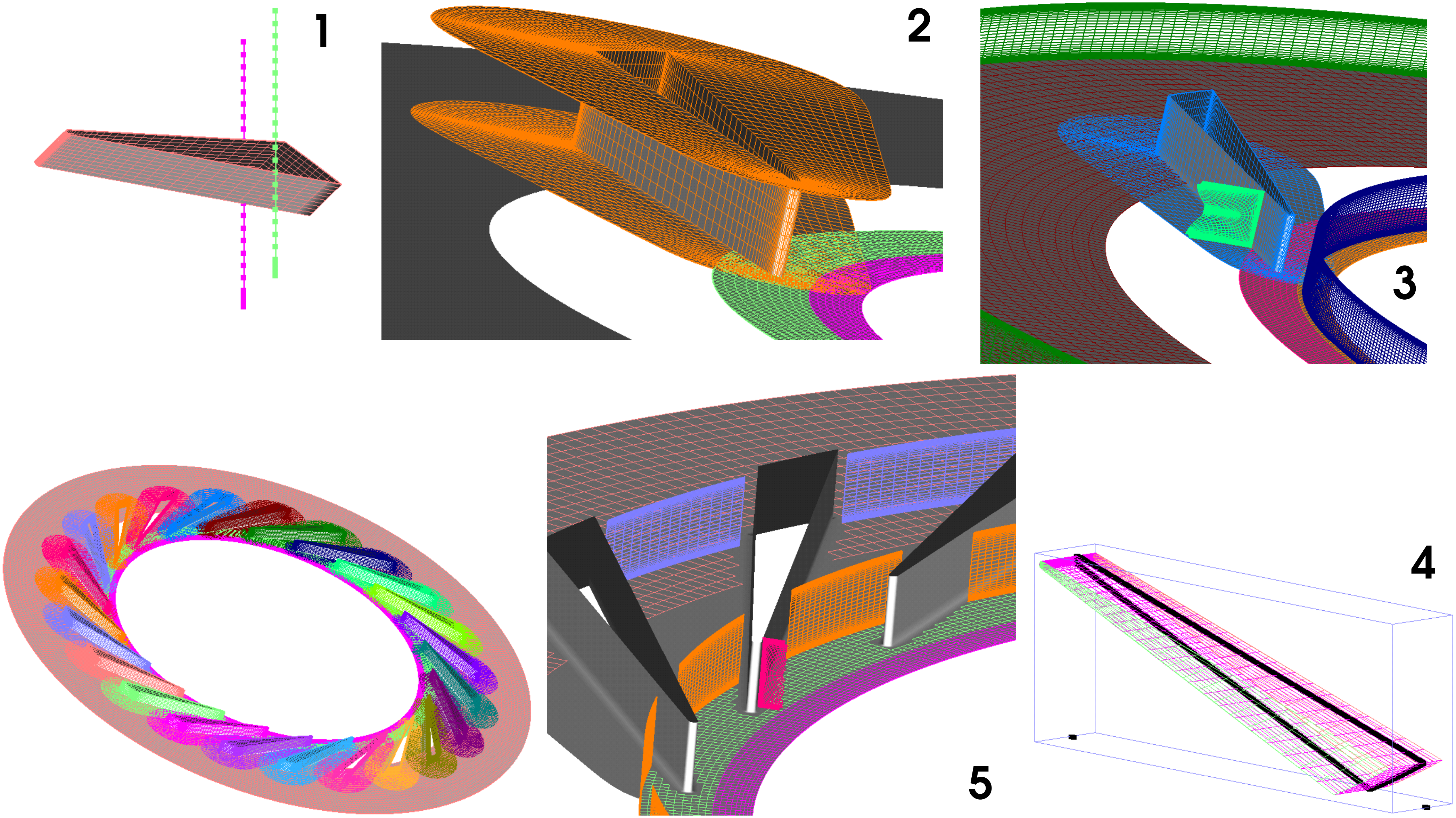
IMPELLER
(M sections, N different blades in each section, tip clearance)



	Manual	Script (fine)	Script (coarse)
No. of pts (million)	19.2	15.2	8.8
User time *	~ 2 weeks	319 sec.	234 sec.

(* from geometry def. to DCF input with SGI R12k 300MHz CPU)

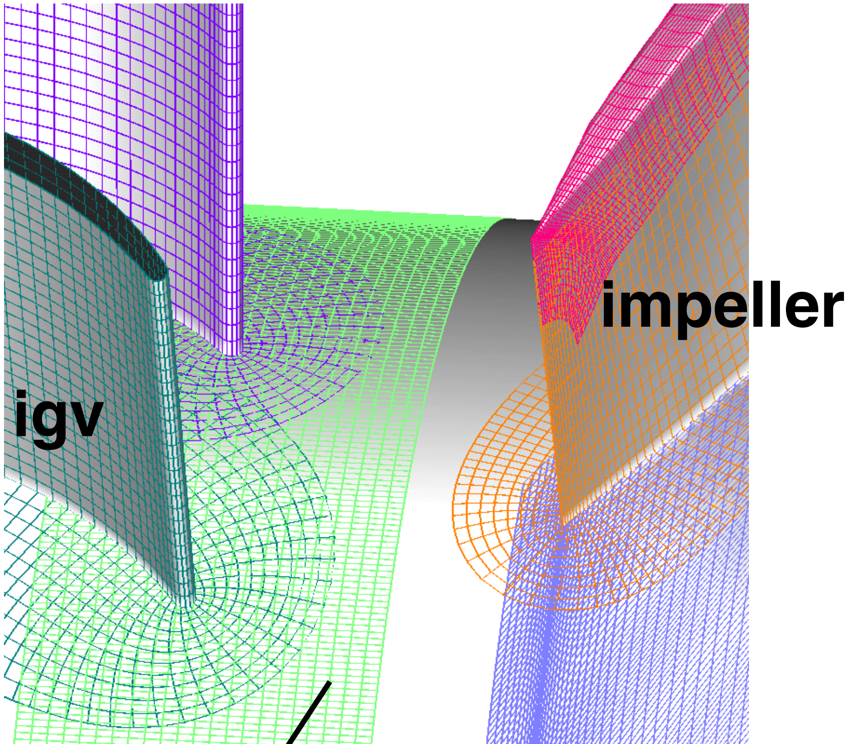
DIFFUSER (N repeated blades, no tip clearance)

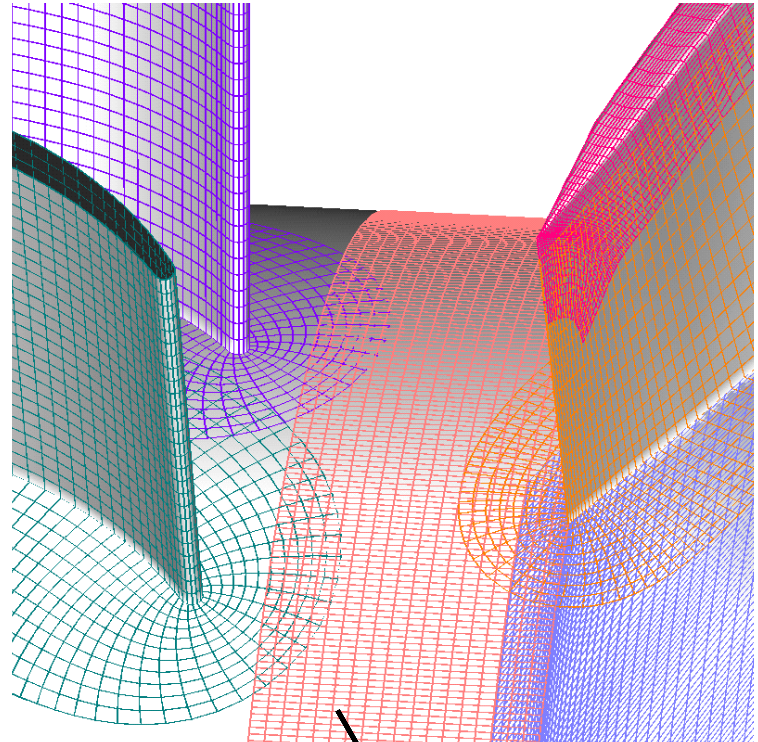


	Manual	Script (fine)	Script (coarse)
No. of pts (million)	8.0	6.4	1.6
User time *	1 day	37 sec.	22 sec.

(* from geometry def. to DCF input with SGI R12k 300MHz CPU)

RING INTERFACE BETWEEN COMPONENTS

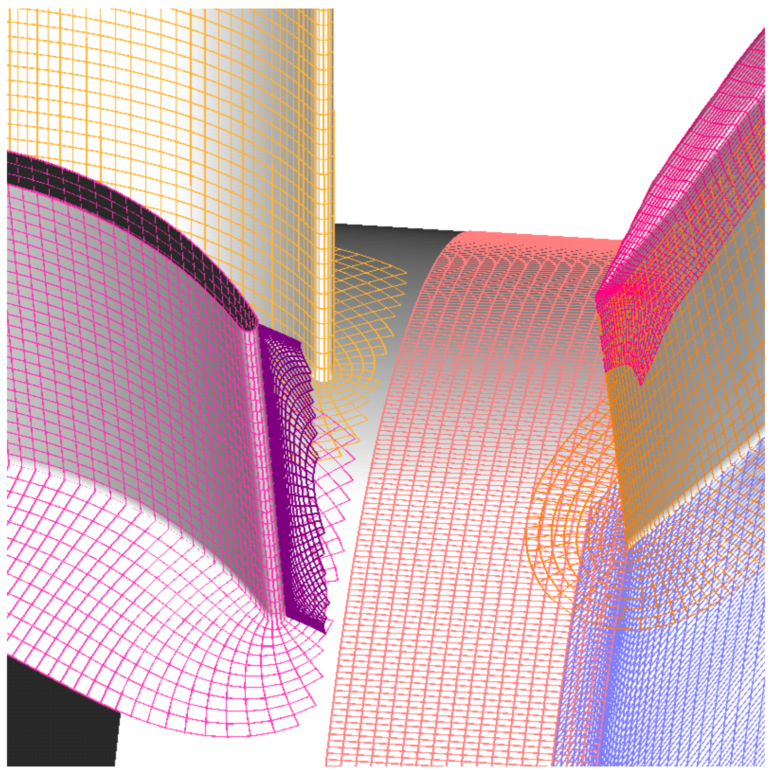




igv outflow ring

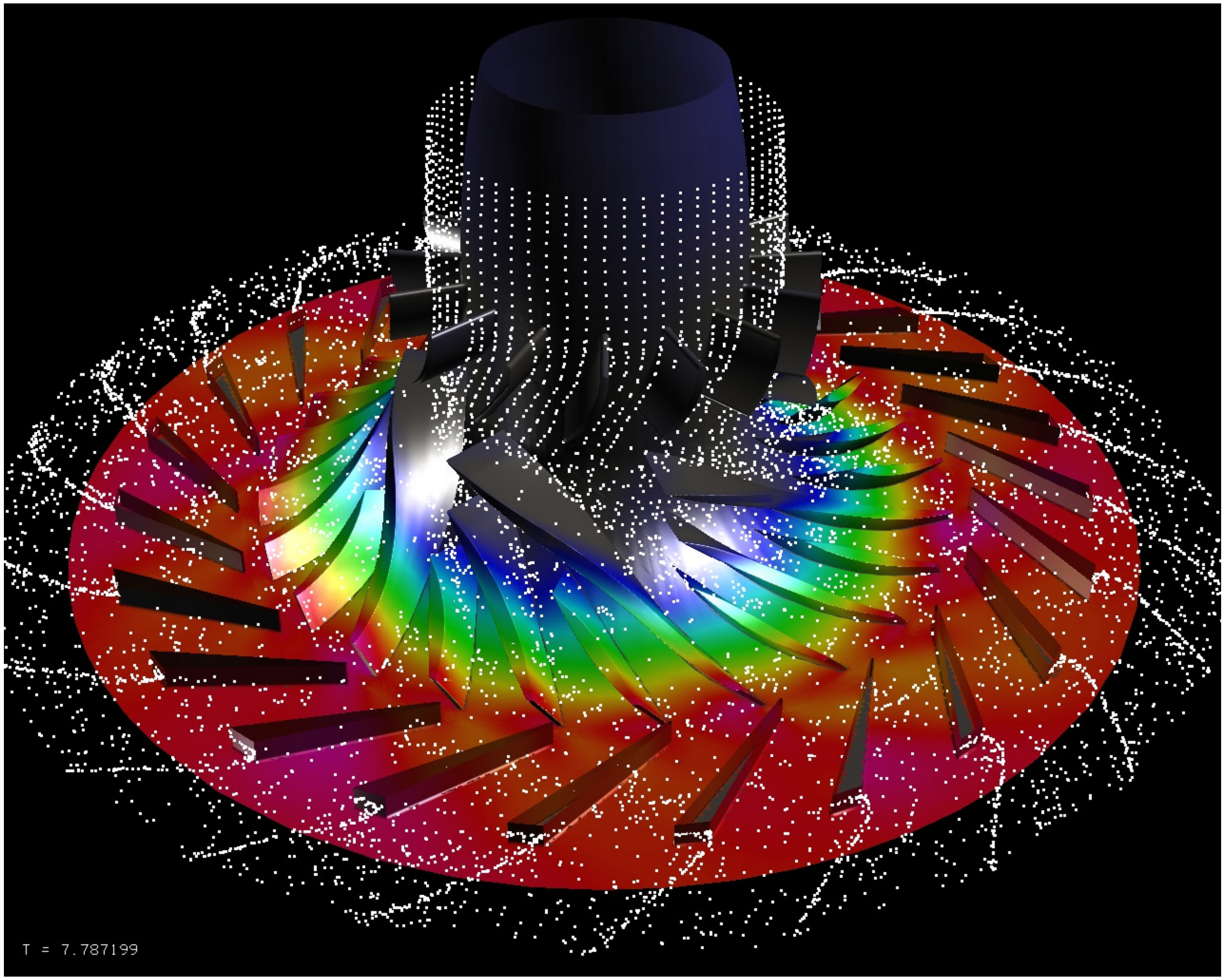
impeller inflow ring

- 9–point overlap between rings
- no impeller points beyond last plane of igv ring
- no igv points beyond first plane of impeller ring



UNSTEADY COMPUTATIONAL RESULTS

Snapshot of particle traces and pressure surfaces near end of third rotation



Grid system – 34 million points

Wall clock time – 3.5 days/rotation on 128 dedicated Origin processors using INS3D–MLP

Kiris, C., Chan, W., and Kwak, D., A Three–Dimensional Parallel Time–Accurate Turbopump Simulation Procedure Using Overset Grid Systems, *Proceedings of the 2nd International Conference on Computational Fluid Dynamics*, Sydney, Australia, July 15–19, 2002.

FUTURE PLANS FOR TURBOPUMP SCRIPTING

- Flow solver input creation in scripts
- More input error checks
- Automatic selection of more parameters
- Further robustness improvements
- Perform more tests on different geometry and parameters
- Documentation
- Graphical interface front end

CRITICAL FUTURE WORK FOR OVERSET TECHNOLOGY

In order for overset technology to gain wider utilization, improvements to the process should be made with the following attributes in mind

	Important	Critical	
Automation	yes	no	
Speed	yes	no	
Robustness	yes	yes	
Low user's effort	yes	yes	e.g., less than about 1 hour's effort on complex geometry

– Low effort and robust surface grid generation

  – surface feature extraction
  – surface domain decomposition
  – auto–surface coverage (grid resolution matching, overlap optimization)

– Low effort and robust domain connectivity

  – hybrid methods
  – fast enough for moving–body problems